Conceptual Design of the Hannover 10m Interferometer for sub SQL measurement

K. Somiya

for Hannover-10m team

GWADW at Ft Lauderdale

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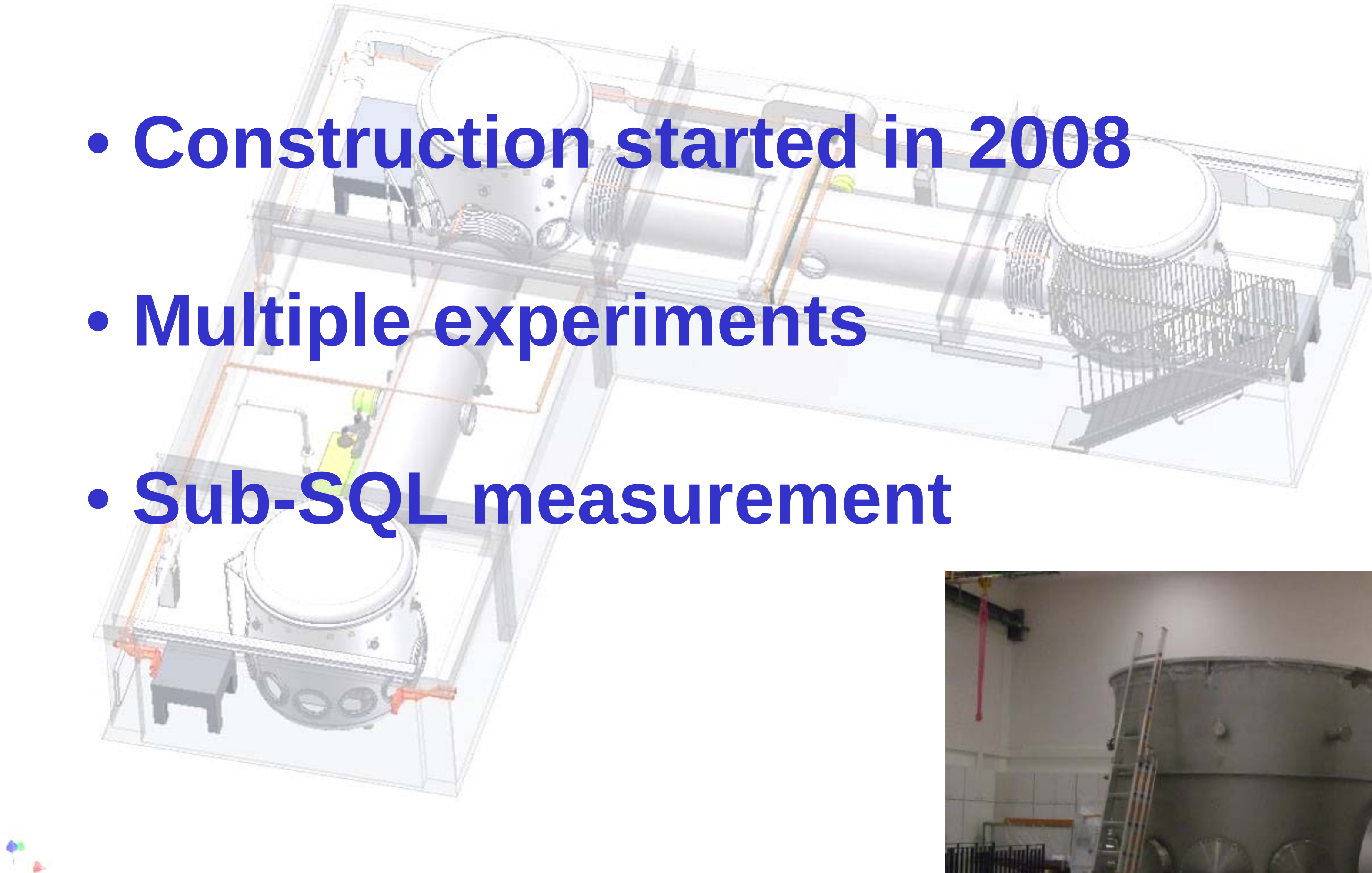
Hannover 10m



- **Construction started in 2008**
- **Multiple experiments**
- **Sub-SQL measurement**

vacuum chamber
ϕ=3m, h=3.2m

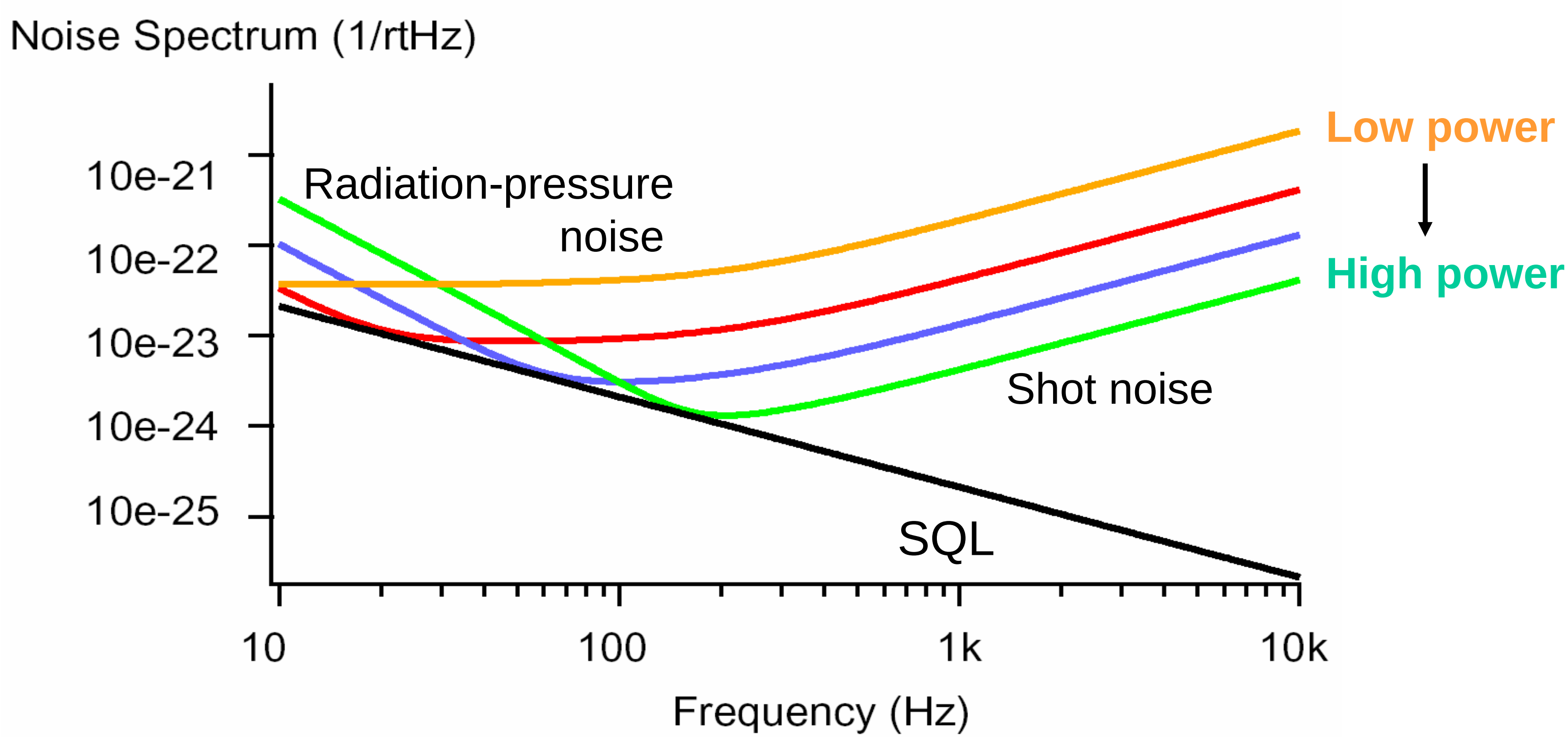
Today's talks for the 10m

1. **Noise analysis and IFO design (K.Somiya)**
   - **SQL**
   - **Reduction of thermal noise**
   - **Parameter optimization**

2. **Discussion of various configurations (F.Kawazoe)**

3. **Overview and status of the experiment (S.Gossler)**

Standard Quantum Limit (SQL)



- **Quantum limit of conventional measurement**

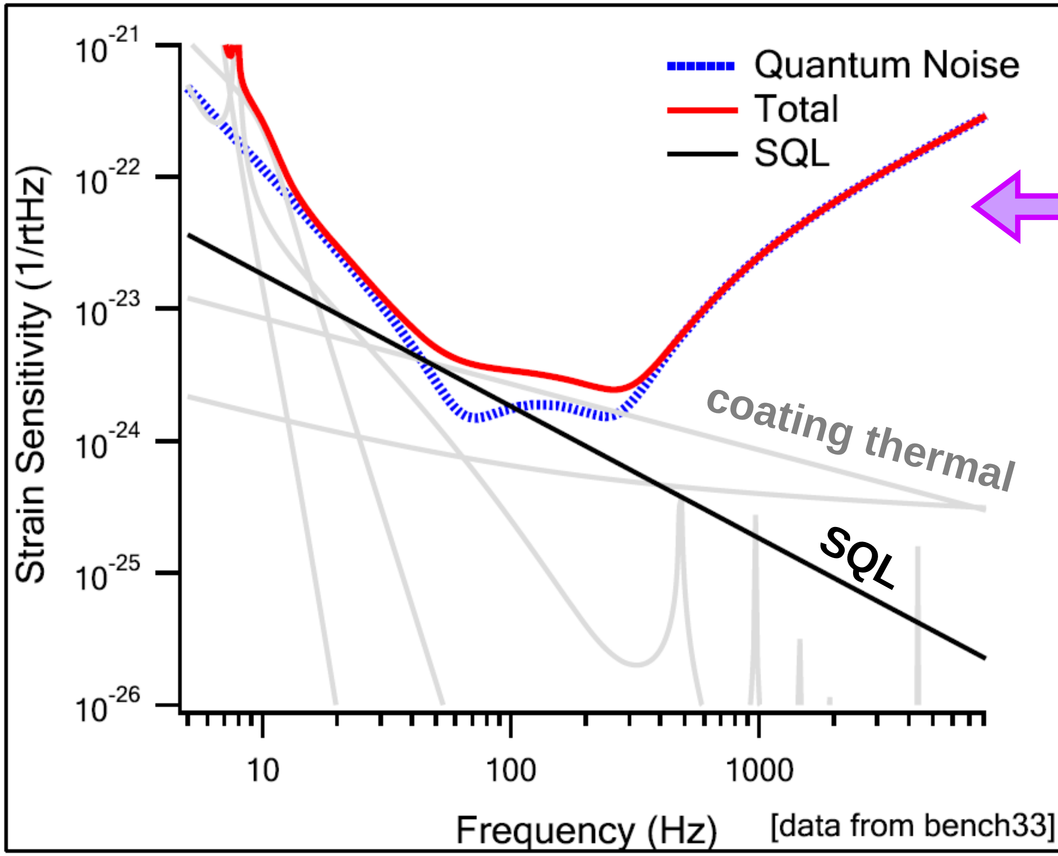
(FPMI w/RF)

- **Ideas to overcome the limit**

(squeezing, homodyne detection, speed-meter, opt-spring, … etc.)

- **Essential to test quantum mechanics**

Can we reach the SQL?



AdLIGO's sensitivity will be close to the SQL

40kg masses are almost in the quantum superposition!!

$$h_{SQL} = \sqrt{\frac{8\hbar}{m\Omega^2 L^2}}$$

- What if we reduce the mass?
- Can we reduce thermal noise?

Mass-dependence of thermal noise

1. SQL and coating Brownian TN

$$\text{SQL} \propto 1/\sqrt{m}$$

$$\text{coating TN} \propto 1/w_0 \propto 1/m^{1/3}$$ **[fixed aspect-ratio]**

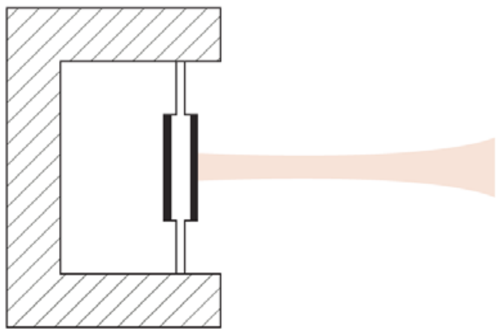
⇨ **Gain is only by m^1/6**

2. SQL and suspension TN

$$\text{susp TN} \propto \begin{cases} 1/m^{3/4}(LF) \\ 1/m^{5/4}(HF) \end{cases}$$ **[fixed wire-thickness]**

⇨ **Susp TN increases faster than SQL**

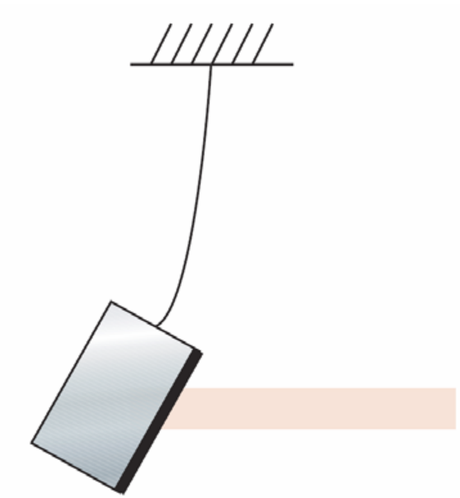
Low-mass regime and high-mass regime



[Low-mass regime]

- high SQL
- high frequency
- low Q, but easy to cool down

300K ⟶ 4K



[High-mass regime]

- high-Q pendulum with dilution by gravity

$$Q = \frac{\text{resonance}}{\text{loss}}$$

resonance ← restoring force: gravity

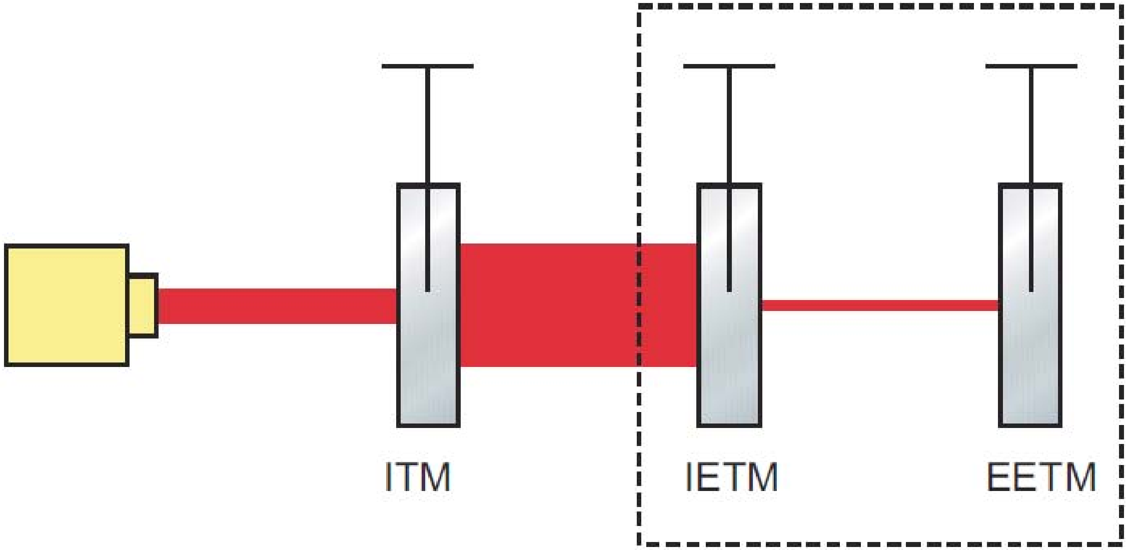
loss ← loss of silica fiber

dilution factor >> 1000

- knowledge from GW detectors
- <u>need to do something to reduce coating TN</u>

Reduction of coating TN with end-mirror cavity

[Khalili PLA 05]



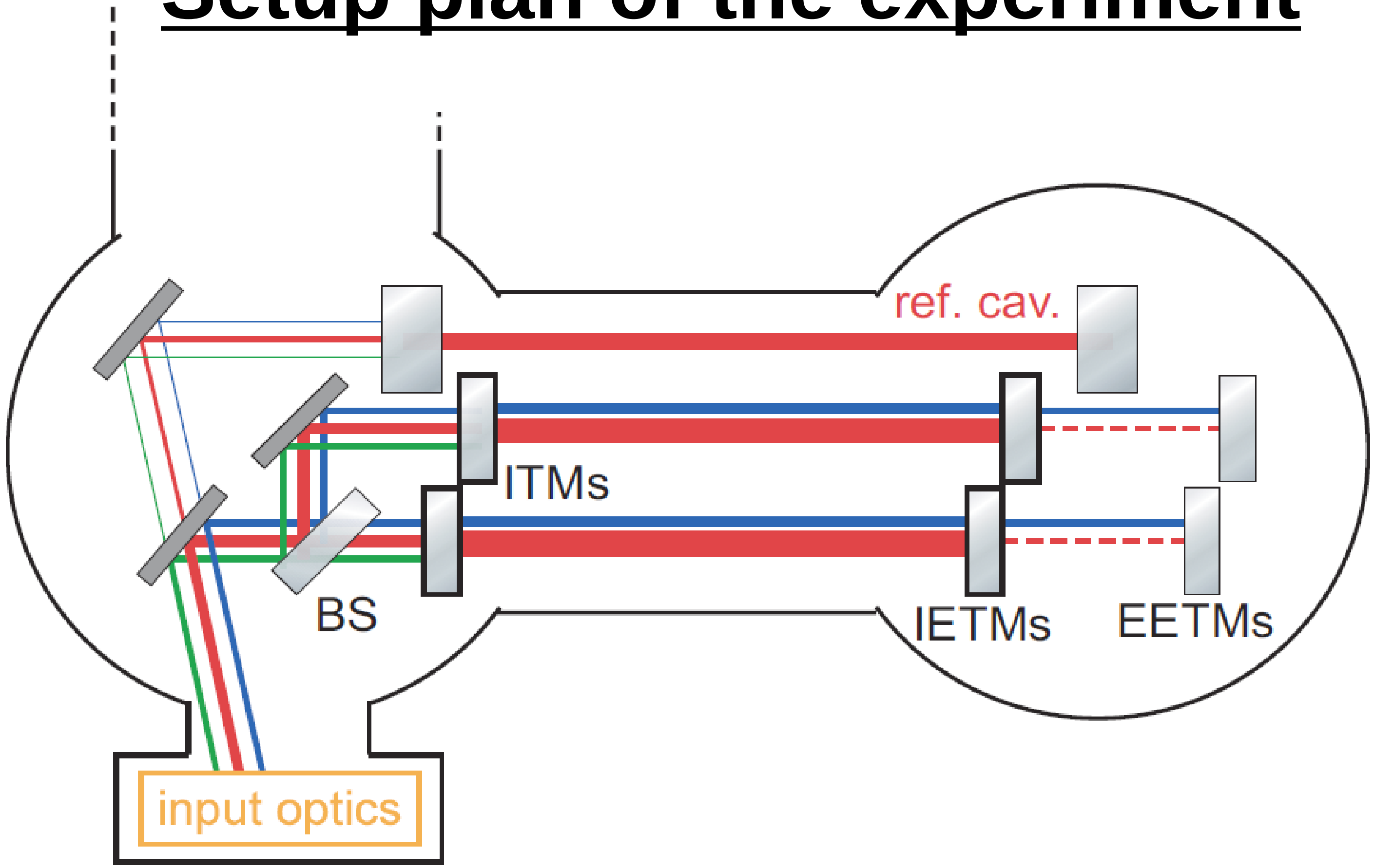
Replacing ETM to an anti-resonant cavity

⇒ less coating on IETM
little noise coupling from EETM

~20% TN reduction with $r_{IETM}=r_{ITM}$

→ **can be better with lower r_{IETM}**

Setup plan of the experiment

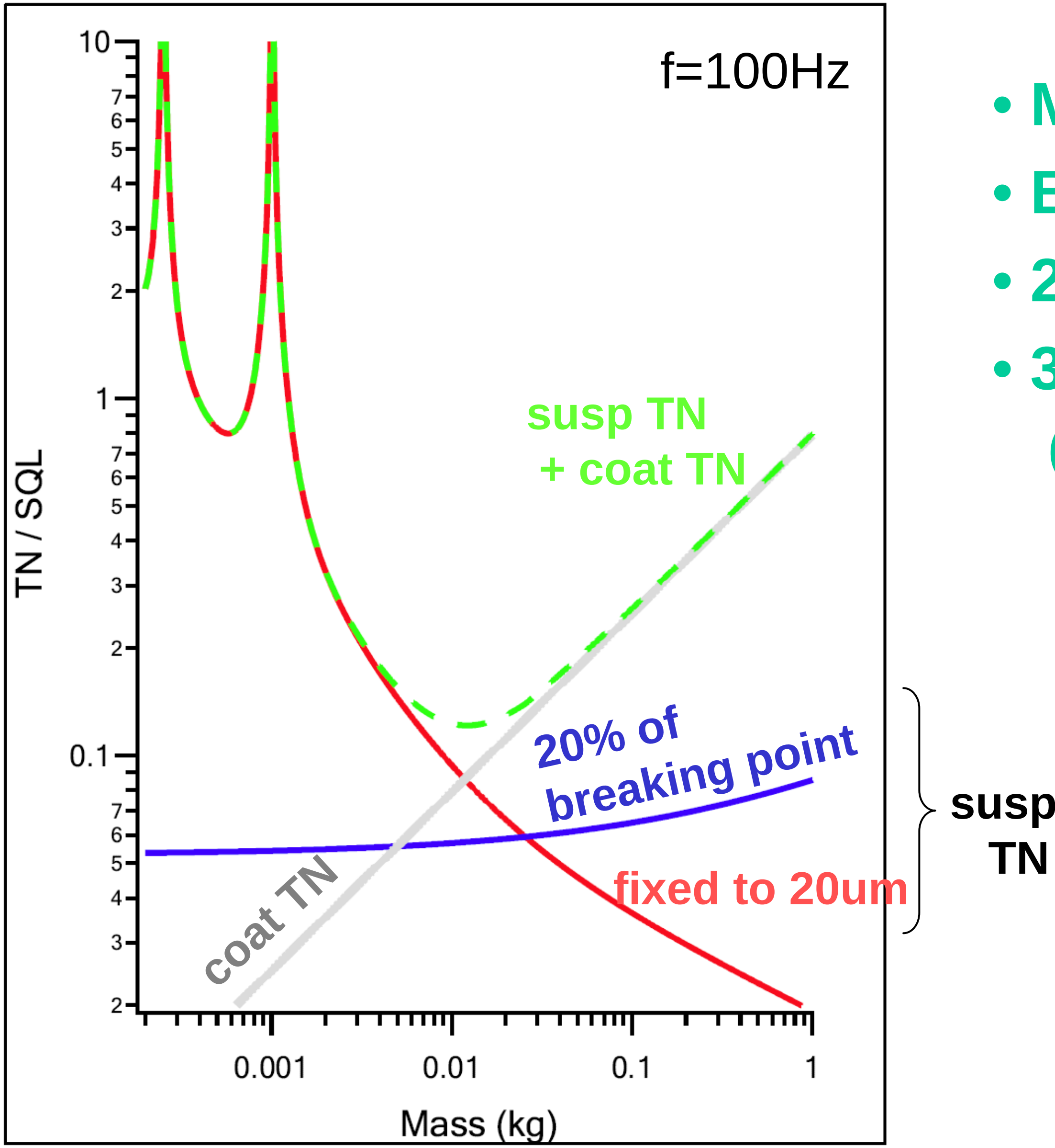


- Folded FPMI with end-mirror cavities
- Ref. cavity with heavy mirrors for freq-stabilization
- Seismic isolation with SAS and SPI

Parameters to be optimized

1. Mass
   - Trade-off of susp-TN/SQL vs coat-TN/SQL
2. Aspect ratio of a mirror
   - Finite-size analysis
3. Reflectivity of each mirror
   - Trade-off of IETM TN vs EETM TN (+ IETM TR noise)
4. Arm length
   - Trade-off of freq noise vs cavity stability

(1) Mass optimization



- Manufacture limit ~ 20um
- Breaking point ~ 2GPa
- 2 fibers on each side
- 30cm length

(1st violin mode = 500Hz w/ m=100g)

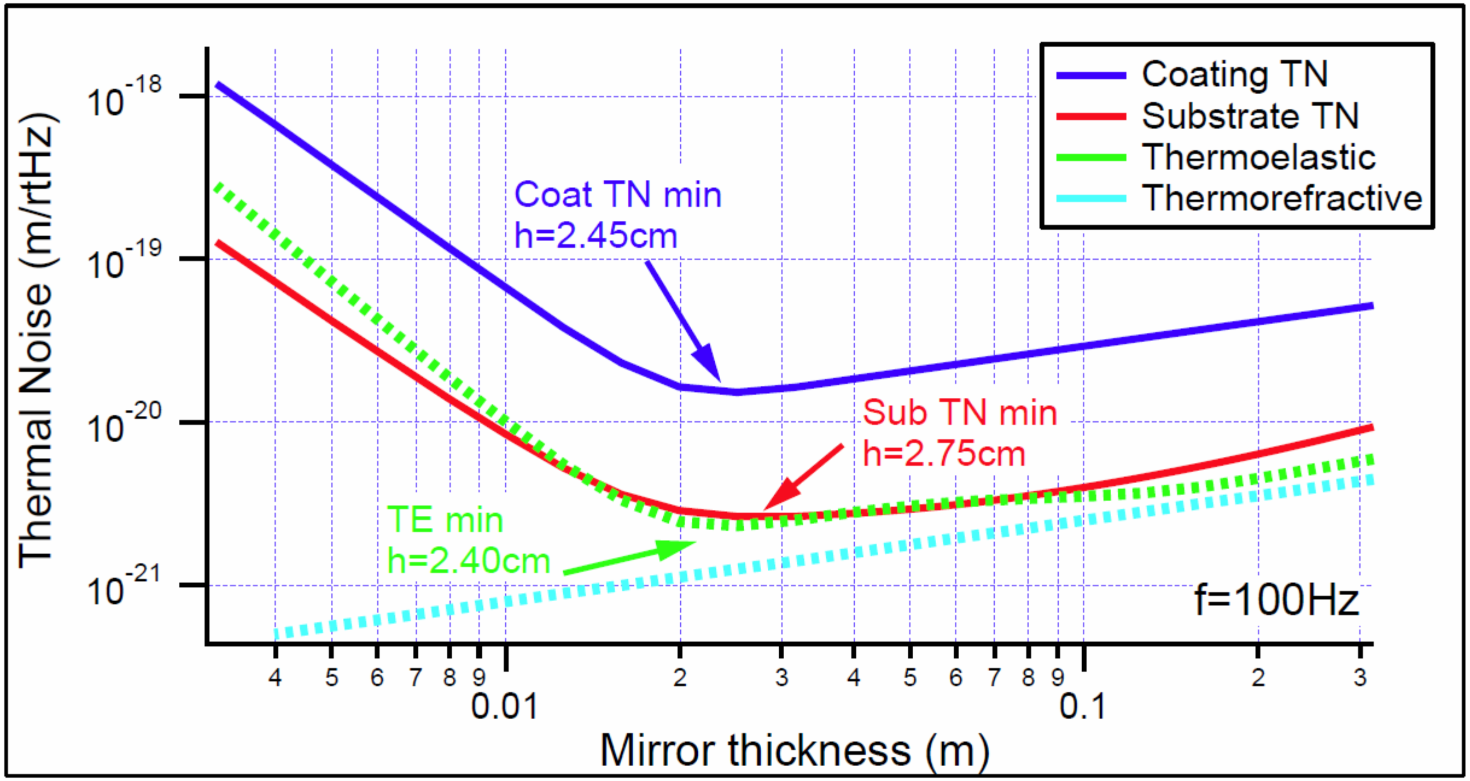
Optimal mass: m=12g

The smaller, the harder.

Our choice: m=100g

(2) Aspect ratio

[Somiya PRD 09]

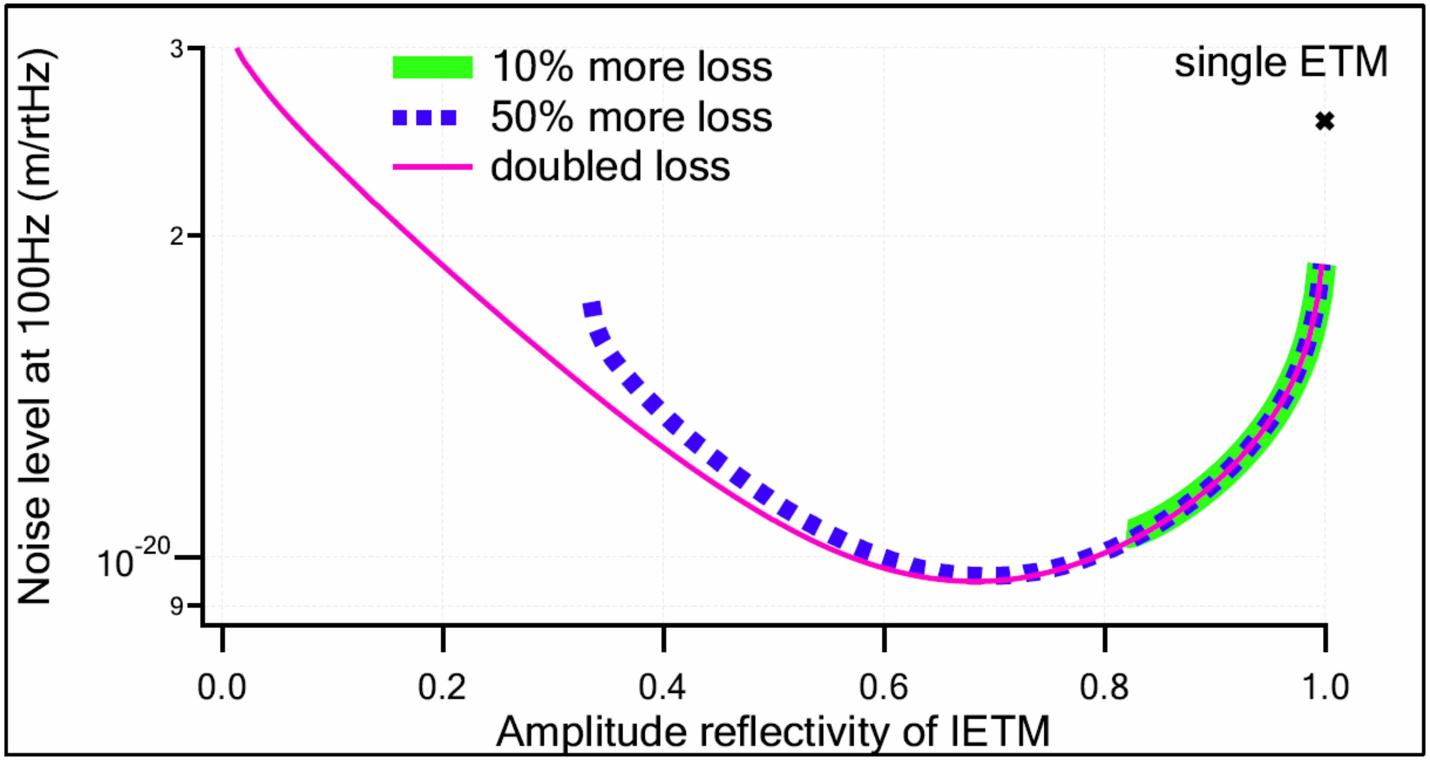


Mass is fixed to 100g. Beam radius is mirror radius/2.5.

- **big h ⟶ small beam radius ⟶ noise increases**
- **small h ⟶ high susceptibility ⟶ noise increases**

Our choice: h=2.45cm, a=2.43cm

(3) Reflectivity optimization



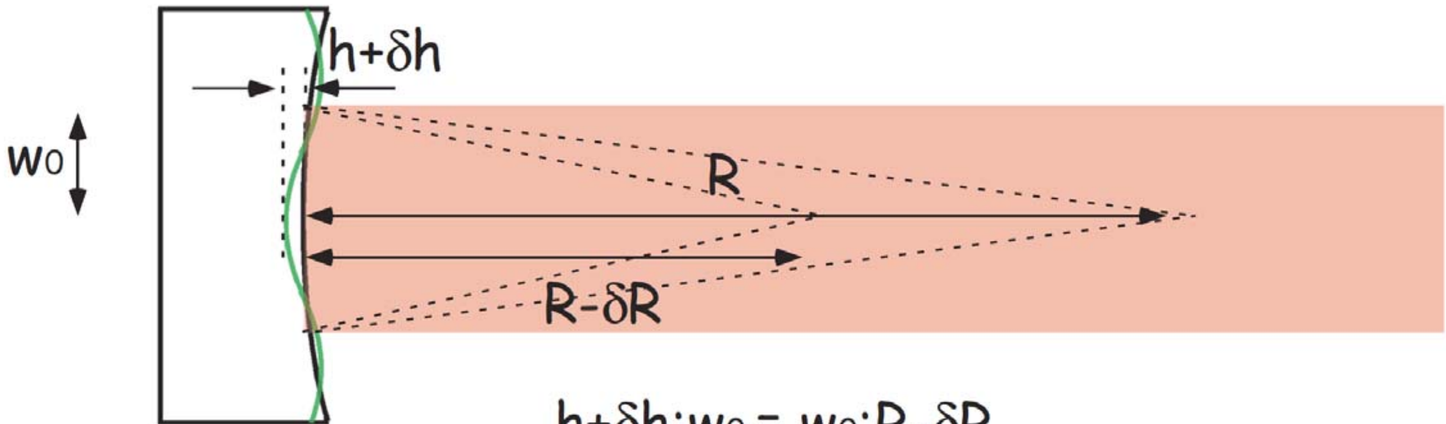
- **high IETM-ref ⟶ more coat TN on IETM**
- **low IETM-ref ⟶ more coat TN from EETM**

(also IETM's substrate thermorefractive)

Our choice: N=2 (r=0.72) for IETM

[N=15 for EETM]

(4) Arm length and cavity stability



h+δh:wo = wo:R-δR

⇨ δh = (wo/R)^2 x δR

Cavity stability :

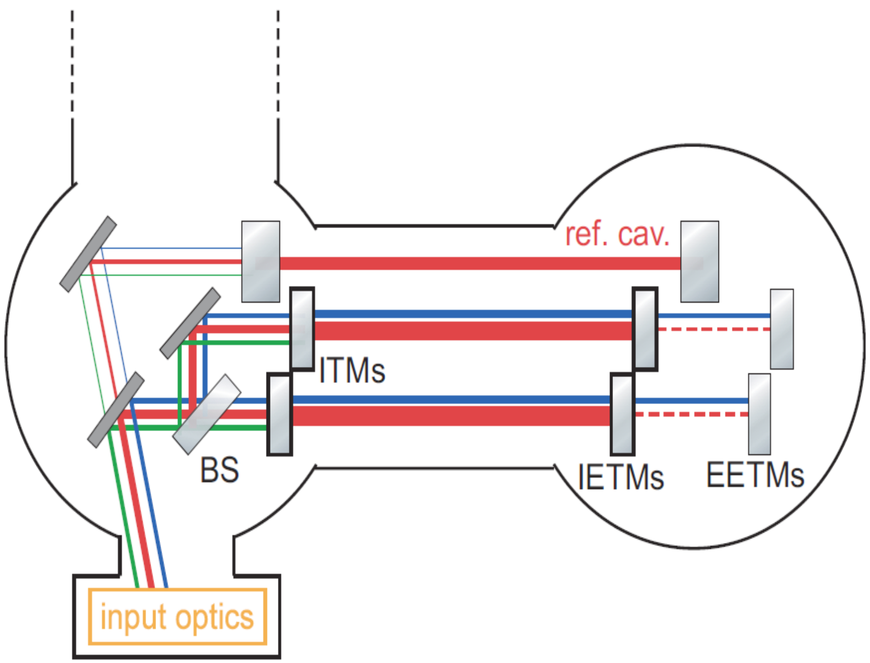
$$w_0 < \frac{\lambda}{\pi}\sqrt{\frac{L}{2\delta h}} \quad \Rightarrow \quad L > 2\delta h\left(\frac{w_0 \pi}{\lambda}\right)^2$$

- **mirror radius / 2.5 = 9.7mm**
- **δh ~ 2nm**

⟹ **L > 3.3m**

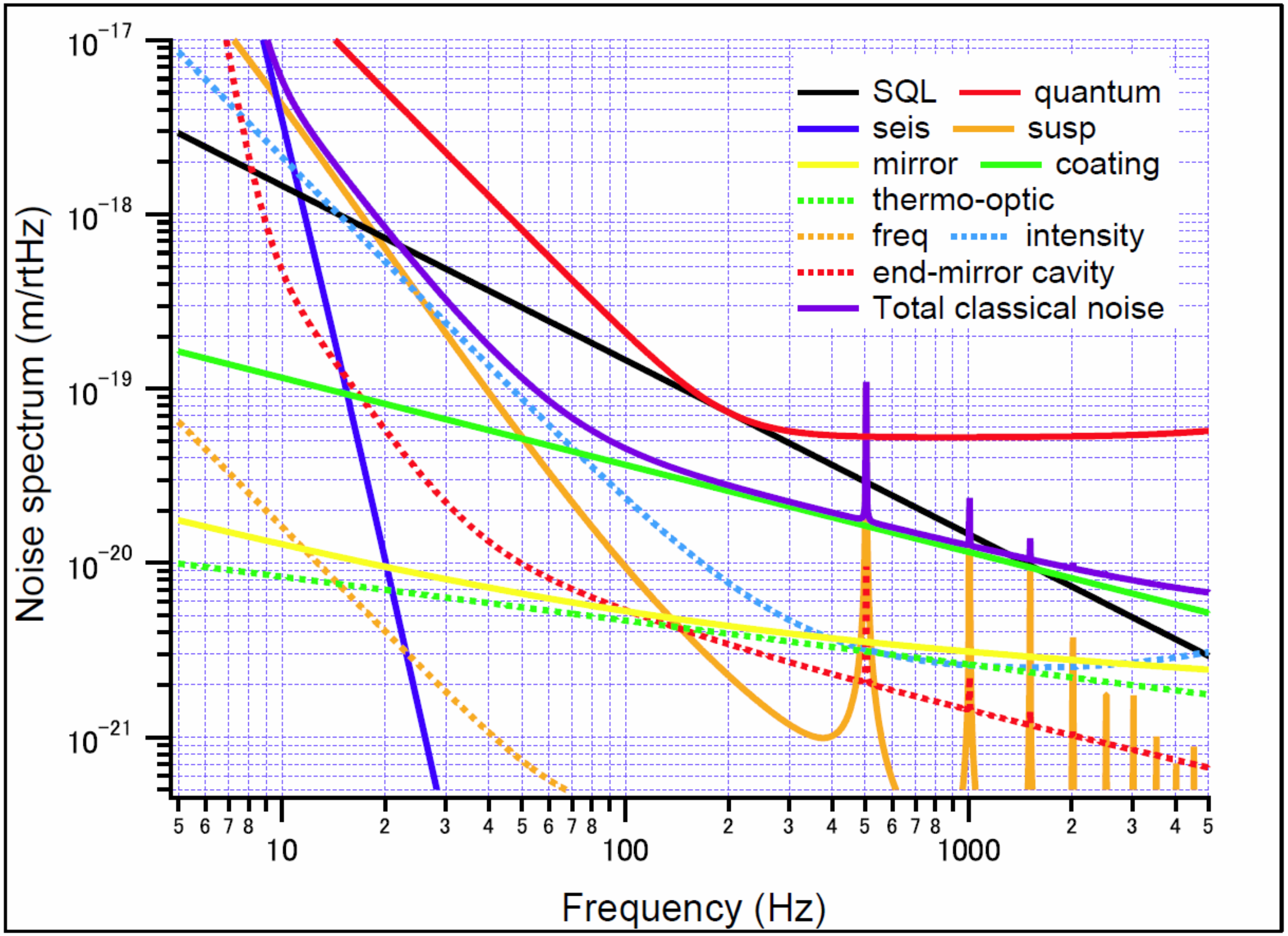
Our choice: L=10m **(1.5m chamber + 10m pipe)**

Parameters are determined



- number of coating layers
  N=8(ITM), 2(IETM), 15(EETM)
  finesse = 600
- L=10m
- m=100g (ϕ2.45cm x 2.43cm)
- input power = 5.5W
  (touching SQL at 200Hz)
- suspension l=30cm, d=28um, N=4
- mechanical losses (at 100Hz)
  susp:6e-7, subs:5e-10,
  coat (silica):1e-4, coat (tantala):4e-4
- ISS: 100mW PD
- FSS: reference cavity
  (F=6000, I=100mW, m=860g)

Estimated noise curve



- SQL is a factor ~3.2 above classical noise (100Hz)!
- Coat TN (ITM) and intensity noise limit the margin

Discussion to increase the margin

Coating TN reduction

- ITM cavity (or power-recycling)
- doped tantala
- non-quarter-wave-length coatings

Intensity noise reduction

- stabilization with L+
- stabilization with squeezing

Mass reduction

- ribbon suspension
- magnetic levitation

End of the slides